Sand Distribution and Statistical Spatial Characteristics on Pacific Reef Platforms

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LONG-TERM GOALS

Our long-term goal is to improve understanding of sand distribution, temporal variability, and response to geologic substrate factors on Hawaiian reef platforms within the depth zone from 20 m to the shoreline.

OBJECTIVES

We are analyzing patterns of sand distribution on the reef platform, and how they are related to morphology. These patterns and surrounding morphology are best understood using spatial analysis tools emphasizing remote sensing. The work consists of several steps including remote sensing analysis, field work data collection, and spatial analysis.

Our top-level goal is to quantify and build a geologic model of the temporal variability and spatial distribution of carbonate sand on fringing reefs. Although waves and currents on fringing reefs mobilize sands they ultimately accumulate under the influence of geologic factors governing hard substrate relief (i.e., karst bathymetry, coral community rugosity, spur and groove development, antecedent topography, etc.). These factors are products of nearshore geologic processes and they exert important controls on the sandy sea floor that work together with dynamic sediment transport processes to determine sand accumulation. We seek to define the relationship between active sand accumulation and reef geologic factors controlling substrate relief.

To do this we have implemented a nested scale analysis using image classification and field data. We identify three domains of study defined by spatial scale: 1) fine-scale classification of individual sandy substrate types in localized portions of the reef surface (< 3m resolution), 2) meso-scale spatial relationships between individual sandy substrate classes and their surrounding hard substrate (between 3m and 10m resolution), and 3) coarse-scale statistical distributions and relationships of sandy substrate classes in a test area, and their correlation with geologic factors governing reef substrate.

Individual pixels and groups of pixels containing elements of particular interest are identified using a linear classification algorithm. By identifying all similar pixels for a class, in this case “sand”, it is possible to quantify the significance of their locations and distribution. Combining these results with bathymetric LIDAR data provides the link between spatial distribution and geologic factors governing substrate relief. Spatial analysis of sandy substrate distribution is conducted using both 2-D Fourier spectral analysis and semi-variograms.

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After images and bathymetry are combined, classified, and analyzed, field sites containing distinct sandy substrate patterns are selected. The objective of all modes of study is the construction of a geologic model defining relationships among and between sand accumulations and substrate geology. The model will emphasize depth, sand thickness, rugosity and relief, oceanographic factors, and geologic controls on substrate characteristics (i.e. karstification, channelization, carbonate accretion, antecedent topography, and hydrologic response).

APPROACH

Step 1 – Remote Sensing Analysis

Methods are focused on developing simple and accurate techniques for sand identification in digital images. Digital images with red, green, and blue components, are the chosen media because they are more common, cheaper, and require less specialized acquisition equipment than hyper-spectral images. Digitized aerial photographs additionally are the only resource available for historical sand variability analysis (an important component of this research). An orthorectified base image is acquired or a digital image is georectified to be a *base image* (Figure 1).

Red, green, and blue bands all have different attenuation coefficients, with the red band penetrating only a short distance through the water column even in optically ideal conditions. To remove the confounding effects of depth within the water column on reflected data, we combine individual color bands with a rasterized LIDAR depth band.

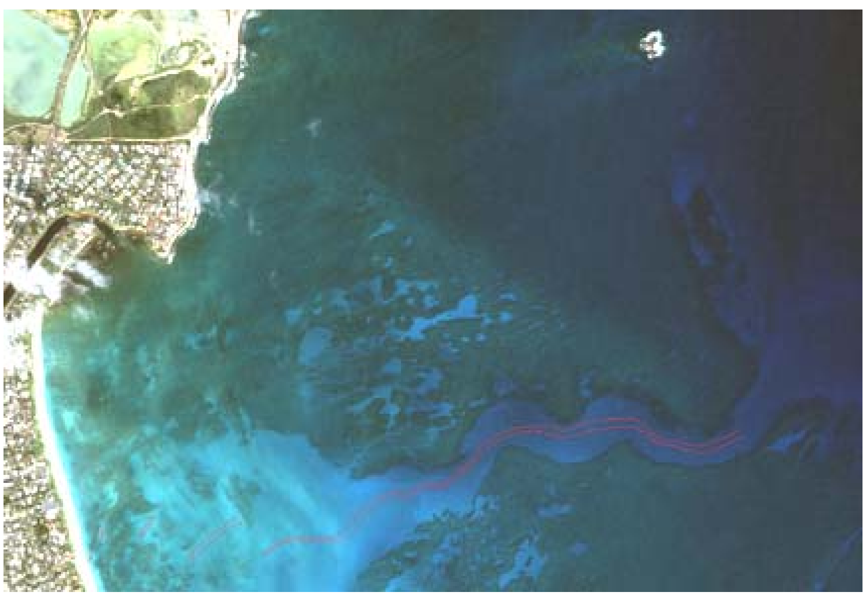

Figure 1 Kailua Bay, Hawaii. This is an orthorectified Quickbird Satellite image with 2.4m pixel resolution. Blue, Green, and Red bands are used for image analysis. The red lines are pixels selected to compute a data rotation with a depth band.

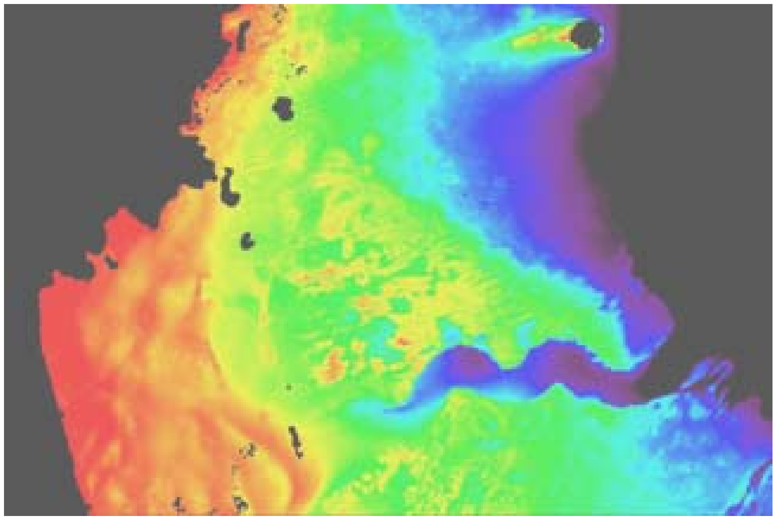

Figure 2 Bathymetry raster for test section of Kailua Bay, Hawaii. Red areas are shallowest, purple areas are deepest, and black sections are masked out to remove land, clouds in the image, and errors in the LIDAR data. This depth image was interpolated at the same pixel resolution and orientation as the digital color image.

LIDAR (USACE SHOALS, *ca* 1999) datasets of the study sites are interpolated into bathymetry surfaces at the same resolution as the image data, and co-registered to the base image (Figure 2). Modern LIDAR point collection in many sites is at almost the same scale as satellite imagery like that provided by Quickbird. Another useful derivative of the interpolated surface is a slope surface, recorded as increased intensity for steeper slopes it provides detailed information on relief and slope variability.

Attenuation in the water column is logarithmic with depth. Each color band is log transformed, creating a linear relationship between the color band and the depth channel, as long as the color band is in optically shallow waters. Each band pair is rotated with a Principal Component Analysis (PCA), maximizing variation in the first component, and then maximizing all remaining variation in a second orthogonal component. The rotation components are computed using the sand pixels identified in Figure 1. Using a single reflector eliminates any variation that would be present from multiple reflectors. Since each color band is paired with depth, the rotation removes any correlation between the color band and depth, leaving a second component that is the color band as if the water column was not present (Figure 3). In the case of the red band, this will not work when looking beyond its optical limits, thus the results from rotating the red band down to 20m are not useful.

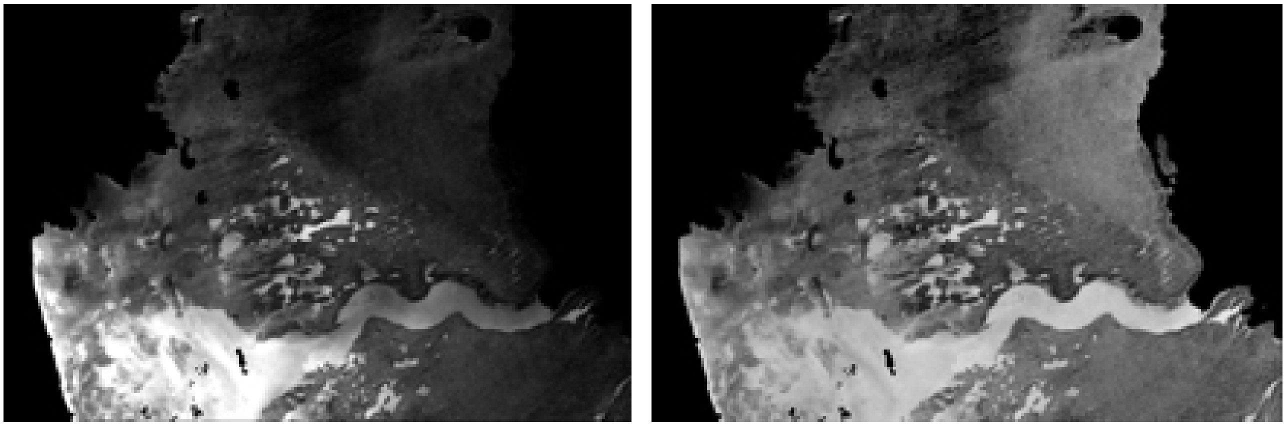

Figure 3 The left image is the original Kailua Bay, Hawaii, Quickbird blue band. The image on the right is the depth decorrelated color image produced by rotating the blue color band and the depth band together, thus removing the confounding effects of the water column.

The new depth decorrelated blue and green bands, as well as the bathymetry band, are then used in the image classification process. We use a linear classification algorithm, because the new log transformed and rotated color channels have linearly separable bottom reflectors. We find this technique to be an effective and efficient tool for rapid segregation of basic substrate information classes, (“sandy substrate class” and “other than sandy substrate class”). The result of the linear classification is a two-information class data set, with the primary information class identifying sandy substrate.

Following classification of the base image, the next remote sensing analysis is to compare classified results against co-registered historical images of the reef surface. This visual interpretation begins to identify the temporal variability of sandy substrate on the time scale of the images. The product of this analysis is a new class, “transient sands”, identified as the mobile sandy substrate that is not present one or more of the images.

Step 2 - Field Data on Sand Thickness

Once sandy substrate locations are identified, their physical characteristics need to be measured and analyzed. Possible testing sites are located in the field, and substrate thicknesses and basic characteristics are measured. Thicknesses are measured using a water-jet probe that passes through the sand to larger rubble or hard substrate. Typically jet-probe points are oriented on a loose grid system, and a random sampling component is added ever three to five grid points. This random sampling is on a much smaller scale than the original grid, and provides additional information needed for spatial analysis in the next step. Basic grain size determinations are inferred from water-jet probing, and finer details are provided from grain size analysis of a few key locations in each area. Thickness measurements are interpolated to produce hard bottom contacts for the sandy substrate (Figure 4).

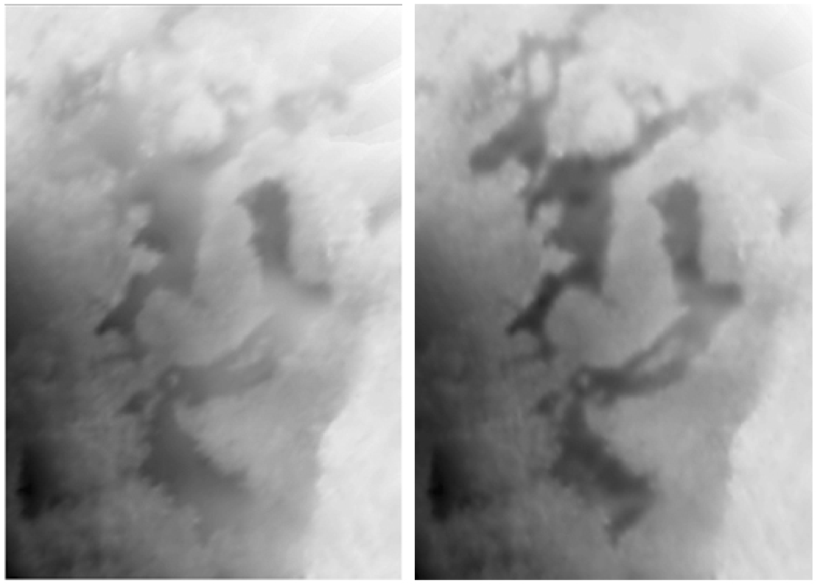

Figure 4 Waikiki, Hawaii. The bathymetry image on the left was interpolated from LIDAR points and is a representation of the sea floor's surface. The image on the right is the same interpolated surface, but with the sand fields removed. This models the hard substrate as if the sand was not present.

Step 3 – Spatial Analysis

A 2-D Fourier Spectral Analysis of test areas is applied to the base image, the classified image, and the slope analysis image. 2-D Fourier Spectral Analysis produces directional and frequency components of each domain by examining changes of intensity within the image. The intensity changes reflect variations in different properties for each of the images (color intensity changes for base image, classes for classified image, and slope variation in slope analysis image).

Semi-variograms are used to model LIDAR and field measured sand thicknesses. Semi-variograms provide information on spatial dependence, preferred orientation, and general relationships among the thickness and depth values. They are also useful for identifying differences between bathymetry surfaces and hard substrate surfaces with sandy substrates removed.

Step 4 – Geologic Model

Finally, combining sand classes from image analysis with interpolated and analyzed LIDAR data, field site surveys, 2-D Fourier Spectral Analysis results, and semi-variogram results produces a detailed description of both sandy substrate and hard substrate spatial and temporal characteristics. These characteristics are cataloged according to the geomorphologic features they occur with on the reef. Small-scale results focus on the individual sandy substrate domains, including 2-D Fourier Spectral Analysis, depth, sand thickness, rugosity and relief. Medium-scale results focus on the statistical relationship of the sandy substrate domain to its surrounding hard substrate. Large-scale results focus on the entire study area, relating sandy substrate domains to oceanographic factors and geologic

controls on substrate characteristics. Other data sets for possible correlation include wave regime data and current environment parameters.

As stated earlier, our research seeks to understand sand accumulation on fringing reefs and how it is influenced by hard substrate morphology. The steps outlined above provide necessary information for the construction of a geological model defining three spatial scales of hard and soft substrate interaction on fringing reefs.

Chris Conger, a master's candidate for Coastal Geology in the Department of Geology and Geophysics at the University of Hawaii, is the primary analyst. Chip Fletcher, professor of Geology in the Department of Geology and Geophysics at the University of Hawaii, is the principal investigator.

WORK COMPLETED

Initial imagery and LIDAR data have been acquired for the Waikiki test site and the Kailua Bay test site. The Waikiki test site is in the final stage, and results are being compiled for comparison to the geomorphology and geology of the area. The Kailua Bay test site is in the latter field data collection and spatial analysis stage.

RESULTS

Advancement in image processing techniques have significantly improved classification results for sandy substrate identification, improving spatial analysis in turn. Recognizing that the slope analysis image was a usable data set for the 2-D Fourier Spectral Analysis was an important factor in correlating sea-floor surface characteristics and sandy substrate distribution characteristics. Use of semi-variogram modeling has improved our understanding of spatial dependence and orientation of sand fields. Removing interpolated sand fields from bathymetric surfaces to create hard substrate surfaces is improving our understanding of hard and soft substrate relationships.

A manuscript describing a portion of this work has been accepted by **Journal of Coastal Research** for publication, and is currently in archived status awaiting revision. An abstract for the work completed on the Waikiki Test Area was accepted for presentation at the **Geological Society of America Annual Meeting** in 2003. An abstract for spatial analysis work completed in Waikiki and Kailua has been submitted for the **American Geophysical Union's** annual meeting in 2004.

IMPACT/APPLICATIONS

This research will improve prediction of the location and interrelationship of sandy and hard substrate on fringing reefs.

RELATED PROJECTS

We are collaborating on bottom characterization with the ONR funded mine burial study. We collaborated with the Department of Land and Natural Resources in a sand resource study on Oahu, Hawaii.

PUBLICATIONS

Conger, C.L., Fletcher, C.H., Barbee, M., 2003. Artificial Neural Network Classification of Sand in all Visible Submarine and Subaerial Regions of a Digital Image. Journal of Coastal Research, Accepted and in Archive Status until revisions are submitted.

Conger, C.L., Fletcher, C.H., Barbee, M., 2003. Marine Carbonate Sand Location and Substrate Morphology Analysis Using PCA and Neural Networks on RGB Images. GSA Annual Meeting.

Conger, C.L., Fletcher, C. H., Hochberg, E.J., 2004. Identification and spatial distribution of remotely sensed sand on fringing reefs of Oahu, Hawaii. AGU Annual Meeting.